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COST ESTIMATION LESSONS LEARNED

FOR

FUTURE SUBMARINE ACQUISITION PROGRAMS

by

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A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

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DISCLAIMER

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Illustrations

Biography

A native of Trenton, New Jersey, CDR O'Harrah graduated with distinction from the United States Naval Academy in 1994 with a Bachelors of Science in Systems Engineering. In May 2003, he graduated with honors from The Wharton School at the University of Pennsylvania with a Masters of Business Administration in Finance.

After completing nuclear power and submarine basic training, CDR O'Harrah reported to the fast attack submarine USS ATLANTA (SSN-712) in October 1995, completing two six-month deployments to the Mediterranean Sea. From March 1999 to July 2001, he served as the Flag Lieutenant to the Commander, Submarine Force U.S. Atlantic Fleet.

Upon graduation from the Submarine Officer's Advanced Course in November 2003, CDR O'Harrah reported to USS SEAWOLF (SSN-21) serving as Navigator/Operations Officer and Engineer Officer. During his tour, USS SEAWOLF completed a first of a kind Selected Restricted Availability and Western Pacific Deployment.

Following the Submarine Command Course, CDR O'Harrah became the Executive Officer of USS WYOMING (SSBN-742) (BLUE) in July 2007 and completed three successful patrol cycles. During his tour the crew earned the 2008 COMSUBRON TWENTY Strategic "S" and Damage Control "DC" awards, the 2007 and 2008 Fleet Forces Command Retention Excellence Award and the 2008 Atlantic Fleet Outstanding TRIDENT Submarine Award.

CDR O'Harrah is entitled to wear the Meritorious Service Medal, Navy Commendation Medal (3 Awards) , the Navy Achievement Medal (3 Awards) and various Unit and Deployment Award. He was a 2009 Regional Finalist for The White House Fellowship. He is currently a member of the Air War College Class of 2010.

Introduction

The passage and signing of the Weapons Systems Reform Act of 2009 indicated the concern of the President and Congress that Major Defense Acquisition Programs (MDAPs) continue to experience cost problems. One of the most significant cost issues is the Navy's $13 billion annual ship building budget. Indeed, the Government Accounting Office (GAO) reported it is not uncommon for estimates to be off by 20 to 50 percent of the acquisition cost[1] and that the Navy exceeded the budget on a total of 41 ships for $4 billion.[2] The *Virginia* class submarine program accounted for approximately $1 billion of this cost overrun on its first two hulls[3].

Unplanned acquisition and operations cost growth impacts the Navy's ability to reconstitute and maintain the fleet as planned. A 2005 GAO report stated that 14 percent of the $52 billion allocated for shipbuilding went to pay for cost growth over the previous five year period.[4] In addition, with the increasing federal deficit, continued war in Iraq and Afghanistan, and need for expansion of other government programs, the days of accounting for cost overruns with additional funding may be disappearing. The new Weapons System Reform Act strengthens the old Nunn-McCurdy requirements for MDAP cost overruns and allows programs to be cancelled if the overruns cannot be justified or if the cost outweighs the benefit of the program. In his signing statement for the bill, President Obama wrote the purpose of the new law was to, "limit cost overruns before they spiral out of control… if they don't provide the

[1] GAO 06-257, "DOD Acquisition Outcomes: a Case for Change," 1.
[2] GAO 07-943, "Realistic Business Cases Needed to Execute Navy Shipbuilding Programs," 1.
[3] GAO 07-943, 5-6.
[4] GAO 05-183, "Improved Management Practices Could Help Minimize Cost growth in Navy Shipbuilding Programs, " 10.

value we need they will be terminated."[5] The cancellation of the F-22 is a recent example of this power being utilized.

The *Virginia* class submarine is the largest shipbuilding program the Navy has.[6] Despite the initial cost overruns, the program has improved its management of the acquisition process and reduced the cost overruns on each succeeding vessel. In 2008 it received the David Packard Excellence in Acquisition Award which is the highest award given by the Undersecretary of Defense for Acquisition Technology and Logistics. The program was recognized for its ability to "reduce life-cycle costs; make the acquisition system more efficient, responsive, and timely; integrate defense with the commercial base and practices; and promote continuous improvement of the acquisition process."[7] While the program has improved its acquisition cost overruns, only one percent of the program's Operating and Support (O&S) funds have been spent, and as a result, the validity of the program's lifecycle estimates have yet to be tested.[8]

The importance of accurately estimating the total ownership costs (TOC)[9] early in major acquisition programs will only increase in the future as budgetary pressures increase. However this is not an easy task. It is difficult to predict the cost of billion dollar weapons systems to be built 10 to 12 years in the future and to predict the TOC of the 30 plus year long program. This task is complicated by politics, changing economic conditions, changing military requirements, and industrial base volatility. Cost estimates need to improve to ensure the necessary resources are appropriated to reconstitute and maintain the Navy's fleet. With the

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[5] Spruill, Nancy, Presentation at the Navy Marine Corps Cost Analysis Symposium, Slide 4. http://www.whitehouse.gov/the_press_office/Memorandum-on-Presidential-Signing-Statements has more information on President Obama's signing statement policy.
[6] GAO-03-895R, "*Virginia* Class Submarine Program", 2.
[7] United States Navy, "Navy's *Virginia* Class Program Recognized for Acquisition Excellence," 8 Nov 2008, http://www.navy.mil/search/display.asp?story_id=40781,
[8] Booz Allen Hamilton, "*Virginia* Class TOC Baseline Discussion Document," Appendix Slide 222, October 2009
[9] The Navy defines Total Ownership Cost using the Office of the Secretary of Defense Operating and Support Cost-Estimating Guide paragraph 2.1 as the life cycle costs – "the sum of four major cost categories, where each category is associated with sequential but overlapping phases of the system lifecycle."

initial cost overruns experienced on the *Virginia* class and the changing and more restrictive fiscal environment, this paper seeks to examine the following issues to develop cost estimate lessons learned for future submarine acquisition programs:

- What was the root cause of the initial *Virginia* Class acquisition cost overruns and could they have been minimized or prevented?
- How do the O&S costs for the *Virginia* class compare to *Seawolf* class and Improved *Los Angeles* Class O&S costs, and does this data effect the validity of the program's cost estimates to date?
- How does the 1995 Program Life Cycle Cost Estimate (PLCCE) compare with the 2010 TOC Baseline Estimate (performed by Booze Allen Hamilton) or the updated NAVSEA 05C PLCCE for *Virginia*?

Figure 1. The Defense Acquisition Management System.

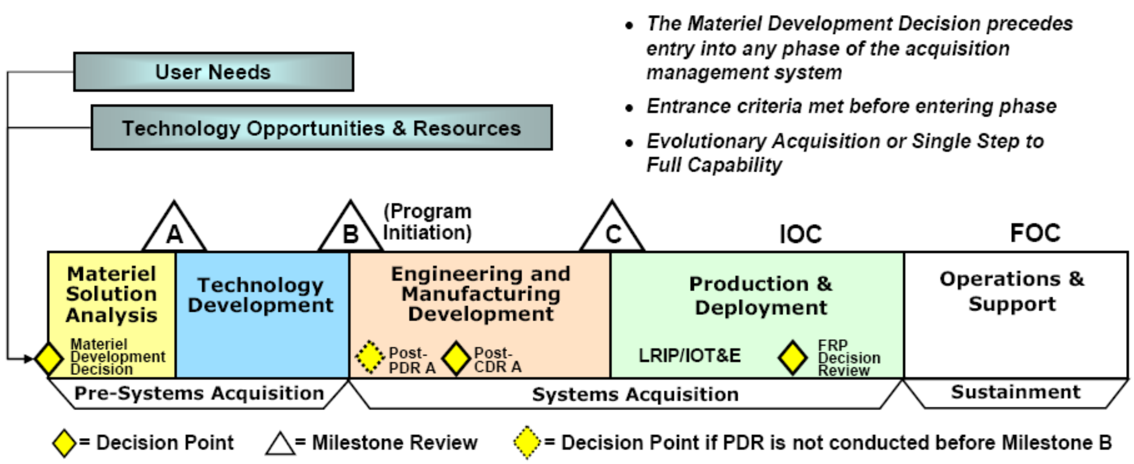

Figure 1[10]

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[10] DOD Directive 5000.02, *Operation of the Defense Acquisition System*, 16.

Major Defense Acquisition Process

Figure 1 describes the phases of an MDAP which are governed by Department of Defense Directives 5000.01 and 5000.02. An MDAP is defined as a program which costs more than $365 million in Research, Development, Test and Evaluation or $2.190 billion in procurement (FY$00).[11] Throughout each of the MDAP phases, there are milestone reviews where the sponsoring program office must provide cost estimates for review by the Office of the Secretary of Defense (OSD). The accuracy of the cost estimates should increase as the program's development progresses. For shipbuilding programs, the lead ship in a class is authorized following the Milestone B decision and its associated program cost estimate is required to be validated by an independent cost estimate.[12] Additional cost reviews are required at Milestone C as well.

Prior to the 2009 Weapons System Reform Act, Congress mandated recertification of MDAPs following cost increases of 15 percent or more. Originally known as a Nunn-McCurdy Breach, the OSD has to recertify the requirement for the MDAP, the accuracy of the revised program cost estimates, and the program's management.[13] Without this certification, funding for the program could be withdrawn. Congress strengthened this process since the original 1982 Nunn-McCurdy bill a number of times, and the most recent changes came with the 2009 Weapon Systems Reform Act. It had the specific goal to terminate programs that could not meet cost goals.[14]

[11] NAVSEA Cost Estimating Handbook, 2-4.
[12] DOD Directive 5000.02, 23.
[13] "Nunn-McCurdy Unit Cost Breaches." 1.
[14] Spruill, Nancy, Presentation at the Navy Marine Corps Cost Analysis Symposium, Slide 3.

Cost Estimate Methods

Acquisition professionals use a number of different methods to perform cost estimates during the acquisition process. Some examples include parametric, analogy, engineering estimate, actual cost, extrapolation, expert opinion and learning curve. Each method has its advantages and disadvantages and different methods are more accurate at different MDAP stages. Appendix A contains a description of these methods from the GAO's *Cost Estimating and Assessment Guide*.

The TOC for a MDAP is the sum of four cost categories: Research and Development, Procurement (acquisition), O&S, and Disposal. Acquisition and O&S costs make up almost 85 percent of a program's total cost. The O&S costs are broken down into Unit Mission Personnel (Manpower), Unit Level Consumption (Direct Unit Operations), Intermediate Maintenance, Depot Maintenance, Contractor Support Services, Sustaining Support, and Indirect Support. Manpower and Depot Maintenance costs are the major costs drivers for submarine O&S costs.[15]

VIRGINIA Class Program History

Throughout the Cold War and following the advent of Naval nuclear power in the 1950s, the nuclear attack submarine (SSN) has been the backbone of the Navy's attack submarine fleet. Able to execute a variety of missions including anti-submarine warfare, anti-surface warfare, intelligence, surveillance and reconnaissance, strike warfare, mine warfare, and special operations, the SSN remains a vital national security asset. During the Cold War, the immense Soviet ballistic missile submarine (SSBN) and SSN threat made anti-submarine warfare the primary US SSN mission. As a result, the *Sturgeon* (1960s construction), *Los Angeles* / 688I

[15] Submarine maintenance conducted by the ship's crew is known as O-Level. I-Level or intermediate maintenance is conducted by an Intermediate Maintenance Activity (IMA). O and I Level maintenance is conducted during a submarine's normal operation cycle. Each submarine class has a maintenance plan periodically scheduling depot maintenance in a public or private shipyard (mostly public) where shipyard level work is performed.

(1970s / 1980s construction), and *Seawolf* (construction commenced 1989) classes were developed to keep US submarines ahead of increasing Soviet submarine capability.[16] However, with the ending of the Cold War, leaders reconsidered future submarine force structure requirements. In 1991, Deputy Secretary of Defense Donald Atwood summarized the state of the US submarine force and *Seawolf* construction relative to the threat, writing, "... in light of changes in the world, the accompanying reductions in threats to American interests and resources devoted to national defense, and the vigorous pace of submarine construction in the past decade, there is no longer a pressing need for production now of a new class of submarines for the US fleet."[17]

Designed to be larger, carry more torpedoes, dive deeper and go faster than previous SSN's, the *Seawolf* was the ultimate Cold War weapon. But its high cost and the Navy's post Cold War focus on littoral water missions made the *Seawolf* class impractical to replace the 688I. The *Seawolf's* high cost caused the DOD to initiate the New Attack Submarine Program (NSSN) in 1991 to prevent inadequate submarine force levels in the future.[18] Later designated the *Virginia* Class, it was designed to be smaller and have a lower TOC than the *Seawolf*. The 1997 NSSN Program Review stated that "from its inception, the NSSN Program has focused on affordability. The challenge has been to maintain crucial attack submarine capabilities while reducing life cycle costs."[19] In a 2004 *Proceedings* article Rear Admiral John Butler claimed

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16 John F. Schank, Mark V. Arena, Paul Deluca, Jessie Riposo, Kimberly Curry, Todd Weeks, and James Chiesa. *Sustaining Nuclear Submarine Design Capabilities*, 11. A detailed account of United States Nuclear Submarine production is contained in pages 7 -13.

17 John Birkler, John Schank, Giles Smith, Fred Timson, James Chiesa, Marc Goldberg, Michael Mattock, and Malcom Mackinnon . *The U.S. Submarine Production Base, 1.*

18 GAO NSIAD 95-4, *Lessons of Prior Programs May Reduce New Attack Submarine Cost Increases and Delays*. 2.

19 "New SSN Program Life Cycle Cost Estimate," 2-5.

that the "*Virginia* class would have the *Seawolf's* stealth, albeit with a 30 percent reduction in total ownership costs."[20]

Electric Boat (Groton, CT) and Newport News Shipbuilding (Newport News,Va) are the only two US shipyards that build nuclear submarines. They are supported by an equally limited industrial base that can be categorized in three separate parts: the nuclear component that provides the parts and materials for the nuclear powered ships; the shipbuilding industrial base made up of the public and private shipyards who build and maintain the nuclear powered warships; and the design industrial base made up of the design engineers.[21]

When the *Virginia* class was being designed, the submarine industrial base was in transition. From 1988 – 1998, 23 688I, 10 *Ohio,* and 2 *Seawolf* class submarines were delivered or scheduled to be delivered. After 1998, only one submarine, the third *Seawolf* submarine, was scheduled for production in the foreseeable future, and its fate was uncertain. As a result, according to Ms. Cynthia Brown, President of the American Shipbuilding Association, "Hundreds of critical system and component manufacturers were forced out of business."[22] According to the Congressional Record Service, approximately "80 percent of the total material procured from construction suppliers (measured in dollars) comes from single or sole source suppliers." [23] Electric Boat and Newport News Shipbuilding were forced to lay off thousands of workers and there was a fear the expertise would be lost on how to build these vessels.

In parallel with the decline in the submarine industrial base, the country struggled with how many submarines the Navy needed to support. Throughout the 1990s the Navy reduced the size of its SSN force by accelerating the decommissioning of *Sturgeon* Class submarines and

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[20] John Butler. "Building Submarines for Tomorrow," 51.
[21] ADM K. H. Donald *Testimony to the House Armed Services Committee*, 13 Jun 2005.
[22] Ms. Cynthia M. Brown, Testimony to the House Armed Services Committee, Subcommittee on Projection Forces, 30 March 2004.
[23] O'Rourke, "Navy Attack Submarine Procurement," 11.

chose to not refuel and decommission some of its first flight *Los Angeles* class submarines. Force structure debates in the late 1990s resolved that 48 SSN's were required,[24] and subsequent Quadrennial Defense Reviews (QDR) sustained the requirement for at least 50 SSN's.[25]

To maintain force structure and meet the QDR requirements, Electric Boat was awarded a contract for detail design and building of the lead NSSN submarine in 1996.[26] The first Milestone A award predicted a cost of $1.5 billion (FY94 dollars) for the first submarine. This plan involved Electric Boat designing and building the lead ship alone. The GAO reported the initial 1994 estimate predicted the NSSN would be $400 million cheaper than the *Seawolf.*

This arrangement meant Newport News Shipbuilding would be left out of the initial production of NSSN's. While the Navy desired a single shipyard to build the submarine to be more cost effective, Congress disagreed. As a result, following an updated cost estimate performed in 1997, Congress directed the *Virginia* class be built via a teaming arrangement between the two shipyards in February 1998.[27] This was done to maintain two shipyards capable of constructing nuclear submarines despite the low procurement rate.[28] Construction began in October 1998 on *Virginia* (SSN 774) and on *Texas* (SSN 775) one year later. The first two *Virginia* class were delivered in October 2004 and March 2006 respectively. To date, six *Virginia* class submarines have been delivered,[29] with 11 total having been procured through FY 2009 and an additional eight more procured for 2010 – 2013.[30] In order to maintain force structure near required levels, it is critical for the Navy to shift to procuring two boats per year.

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[24] O'Rouke, "Navy Attack Submarine Procurement", 7. As of the end of 2008 current SSN force structure is 53.
[25] Department of Defense. *Quadrennial Defense Review,* 1 Feb 2010, xvii. The 2010 QDR requires 53 – 55 SSN's.
[26] GAO 05-183, *Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*. 63.
[27] GAO 05-183, 63.
[28] O'Rourke, pg. 10.
[29] *Virginia, Texas, Hawaii, New Hampshire, North Carolina* and *New Mexico*
[30] General Dynamics Electric Boat "U.S. Navy Awards General Dynamics $14 Billion Contract for Eight Virginia-Class Submarines," 22 December 2008.

At a cost of $2 billion (FY05 dollars) per submarine, buying two submarines per year uses over one-third of the Navy's total annual ship building budget. [31] The 2011 Federal Budget requests funding for two *Virginia* class submarines. This shift to two per year is ten years beyond the original planned shift to two per year procurement.[32]

Virginia Class Cost Estimate History

One of the Navy's goals with the *Virginia* class was to reduce the overall cost per submarine compared to the *Seawolf.* The Center for Naval Analysis performed the Milestone A cost estimate for the NSSN in 1993. That report stated 30 NSSNs would cost $45 billion or roughly $1.5 billion per ship in FY94 dollars.[33] This analogy estimate used historical data from the *Seawolf* and *Los Angeles* classes.[34] Escalating this estimate into FY05 and FY10 dollars raises the cost to $1.78 billion per ship and $1.97 billion per ship respectively. The total acquisition cost of the program would be $59 billion for 30 ships in Fiscal Year 2010 dollars.[35]

This estimate was later updated with a 1995 PLCCE for the Milestone B evaluation. It included the first estimate for the entire program life cycle. The estimate was a combination of a bottoms up and actual cost analysis that was validated using a parametric estimate.[36] The estimate assumed a procurement schedule of two boats every three years from 1998 – 2003, and then a combination of two or three submarines per year starting in 2005.[37] The parametric estimate used Cost Estimating Relationships (CER)[38] from the *Seawolf* and 688I class costs. The

[31] United States Navy, 2010 SCN Budget Justification Book, 3.
[32] William Hillardes, "2 for 4 in 2012 The *Virginia* Class Road Ahead", 68. This article contains further discussion on the NAVSEA PMS 450 efforts to achieve the two per year acquisition of *Virginia* class submarines.
[33] GAO NSIAD 95-4, 2.
[34] GAO 05-183, 63.
[35] Navy Center for Cost Analysis Joint Inflation Calculator January 2010 Version. NAVY SCN Escalation Factor: (1994 – 2005): 1.1835 ; (1994 – 2010):1.3142.
[36] "New SSN Program Life Cycle Cost Estimate," 2-1.
[37] "New SSN Program Life Cycle Cost Estimate," 2-2.
[38] See Appendix A or GAO *Cost Estimating Guide* for more information on CERs.

conclusions from the PLCCE in FY 95, 2005 and 2010 dollars are shown in Tables 1 and 2. The estimate used the fifth ship because "it shows a more meaningful comparison of NSSN costs."[39]

1997 Program Life Cycle Cost Estimate (Billions of Dollars)							
	RDT&E	Production Total	Production Lead Ship	Production 5th Ship	Operating and Support	Other	Total Program
FY 95	3.4	43.9	1.9	1.7	31.6	1.4	80.3
FY 05	4.0	51.0	2.2	2.0	41.2	1.6	97.8
FY 10	4.4	56.6	2.5	2.2	50.2	1.8	113.0
Escalation Factors							
95 - 05	1.1639	1.1614	1.1614	1.1614	1.3038	1.1614	
95 - 10	1.2929	1.2897	1.2897	1.2897	1.5875	1.2897	

Table 1[40]

1997 NSSN Operations and Support Estimate						
Operations and Support (Annual Estimate in Millions)	**Per Ship Annually**			**Program Life Total assumes 33 years / 30 Ships**		
	FY 95	**FY 05**	**FY 10**	**FY 95**	**FY 05**	**FY 10**
Unit Mission Personnel	5.16	6.73	8.20	5,112	6,665	8,116
Unit Level consumption	3.17	4.13	5.03	3,135	4,088	4,977
Intermediate Maintenance	1.99	2.59	3.15	1,965	2,562	3,120
Depot Maintenance	11.20	14.60	17.78	11,086	14,454	17,599
Contractor Support Services	0.009	0.01	0.01	9	12	14
Sustaining Investment	4.41	5.75	7.00	4,363	5,688	6,926
Indirect Support	5.96	7.77	9.46	5,900	7,693	9,367
Total	31.89	41.58	50.63	31,571	41,162	50,119
Escalation Factors		1.3038	1.5875		1.3038	1.5875

Table 2[41]

The O&S estimate used a model which assumed a thirty ship class with a service life of 33 years. Throughout the ship's life it would require 38 months of depot maintenance.[42]

39 "New SSN Program Life Cycle Cost Estimate," 2-2.
40 Table Data Source: "New SSN Program Life Cycle Estimate," 2-3. Data escalated using Joint Inflation Calculator January 2010 Version.
41 Table Data Source: New Attack Submarine (NSSN) O&S Cost Estimate for FY 97 Program Review – Volume II, 9 September 1997, New SSN O&S – by CAIG. Data escalated using Joint Inflation Calculator January 2010 Version.
42 New Attack Submarine (NSSN) O&S Cost Estimate for FY 97 Program Review – Volume II, 9 September 1997 Input Data Sheet.

Virginia Class Initial Acquisition Cost Estimate Errors

The GAO reported in an assessment of Navy shipbuilding programs, that the Navy budgeted $3.1 billion for the *Virginia* (SSN-774) and cost overruns required an additional $422 million. The total cost of the lead ship was $1 billion (FY05 dollars) over the 1997 estimate.

The report analyzed the failure and concluded the contract was negotiated at less than the shipbuilder's cost estimates because the "program officials were constrained to negotiating the target price to the amount funded for the program, and as a result, risked cost growth from the outset." [43] Although the shipbuilders agreed to attempt to minimize costs, the terms of the contract protected the shipbuilder from any cost overruns. The GAO reported the growth was due to material and man hour growth. The excessive error of the 1997 lead ship cost estimate was exacerbated because it utilized a 23 percent vendor adjustment due to a six year gap in submarine production.[44] According to the GAO, no study was done to validate 23 percent estimate used in the PLCCE. This difference in material costs accounted for over 80 percent of the total cost growth.[45]

The lesson learned is not that the vendor adjustment was estimated incorrectly. It is the failure to perform a study to quantify the vendor risk after the program office recognized dramatic changes had occurred in the submarine industrial base due to the near halt in submarine production. As a result, the estimators were off by three times the amount (60 percent instead of 20 percent).

The question not addressed by the GAO report is why the validation process did not catch the problem. The conclusion this author draws is that the historically based CERs developed

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[43] GAO 05-183, 24.
[44] "New SSN Program Life Cycle Cost Estimate," 4-4.
[45] GAO 05-183, 65.

using SSN-21 and SSN 688I data did not account for the change in the industrial base either. As a result, unrealistic CERs caused a poor validation, and the risk associated with the cost estimate was not recognized.

Virginia Class Acquisition Cost Growth Improvement[46]				
Dollars in Millions (FY 05)				
Hull Number	**Initial Budget**	**Actual Budget**	**Cost Growth**	**Cost Growth %**
774	3,260	3,682	422	13%
775	2,192	2,740	548	25%
776	2,020	2,183	163	8%
777	2,276	2,332	56	2%
778	2,192	2,242	50	2%
779	2,152	2,255	103	5%
780	2,245	2,289	44	2%
781	2,402	2,378	-24	-1%
782	2,612	2,604	-8	0%
783	2,654	2,654	0	0%

Table 3

As a consequence of the cost overruns on the two ships a Nunn-McCurdy breach occurred.[47] The class is now forever labeled by government oversight agencies like the GAO as a problem program (even though cost overruns with each ship have improved.) The GAO's method to measure program effectiveness uses the Milestone B cost estimates (prior to production) so once a program performs poorly, it is impossible to redeem itself.[48] Table 3 shows the dramatic improvement achieved by the *Virginia* Class program in cost growth with the subsequent ships. In addition, the fifth ship cost is within $100 million of the 1997 fifth ship estimate (escalated to FY05 dollars). However, it remains one of the Department of Defense's Top 10 Cost Growth programs.[49] But this acquisition success has enabled the *Virginia* Class Program Office to prove

[46] Data for Table 2 came from GAO Reports 05-183, pg 64 and GAO 07-943 pg 22.
[47] Department of Defense, *SSN 774 (Virginia Class) Selected Acquisition Report*, 31 December 2007, 5.
[48] Spruill, Slide 20.
[49] Spruill, Slide 24.

they can predict the costs of the subsequent submarines and provide Navy planners confidence in the fidelity of future procurement strategies.[50]

Virginia Class Operations and Support Cost Comparison

One of the *Virginia* class's goals was to reduce life cycle costs. To see if *Virginia* Class was achieving this goal, Navy Visibility and Management of Operating and Support Cost (VAMOSC) data from the Naval Center for Cost Analysis was reviewed for all 688I, *Virginia* and *Seawolf* class SSN's from 1994 - 2008.[51] All data was obtained in (FY10 dollars). An average 688I cost and a 688I average cost for that year was developed. These values were graphed along with *Seawolf* and *Virginia* class submarine data by hull. The O&S costs for *USS Greeneville* (SSN 772), the second to last 688I commissioned, was also graphed. This was done to provide a single 688I's O&S costs as close in age as possible to the *Seawolf* and *Virginia*. Graphs of all 688I data used for this project are included as part of Appendix C. The third *Seawolf*, *USS Jimmy Carter* (SSN-23), was not used in the analysis because it was modified with a Multi-Mission Platform (MMP). The MMP made the submarine much larger than the other two *Seawolf* submarines changing its operating characteristics, maintenance requirements and crew size. As a result, its costs are not comparable to other SSNs.

VAMOSC data does have its limitations. It depends on the accuracy of the data reported and anomalies are supposed to be noted when they occur. In addition, certain Naval Nuclear Propulsion Program costs, including refueling overhaul costs, are not accounted for in VAMOSC data. However, since the SSN 21 and SSN 774 have life of the ship reactor cores, the lack of 688I refueling overhaul data will not affect this comparison.

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[50] Hilardes, 68.
[51] RAND Corporations, *The U.S. Submarine Production Base* analyzed SSN operating and support data prior to 1991. Appendix G contains their conclusions.

Figures 2 through 7 display a comparison of the VAMOSC data for TOC. From these figures the following conclusions can be drawn.

Depot maintenance drives the annual operating costs for a submarine. Almost one-half (43 percent) of the total annual operating costs from the 23 688I submarines studied come

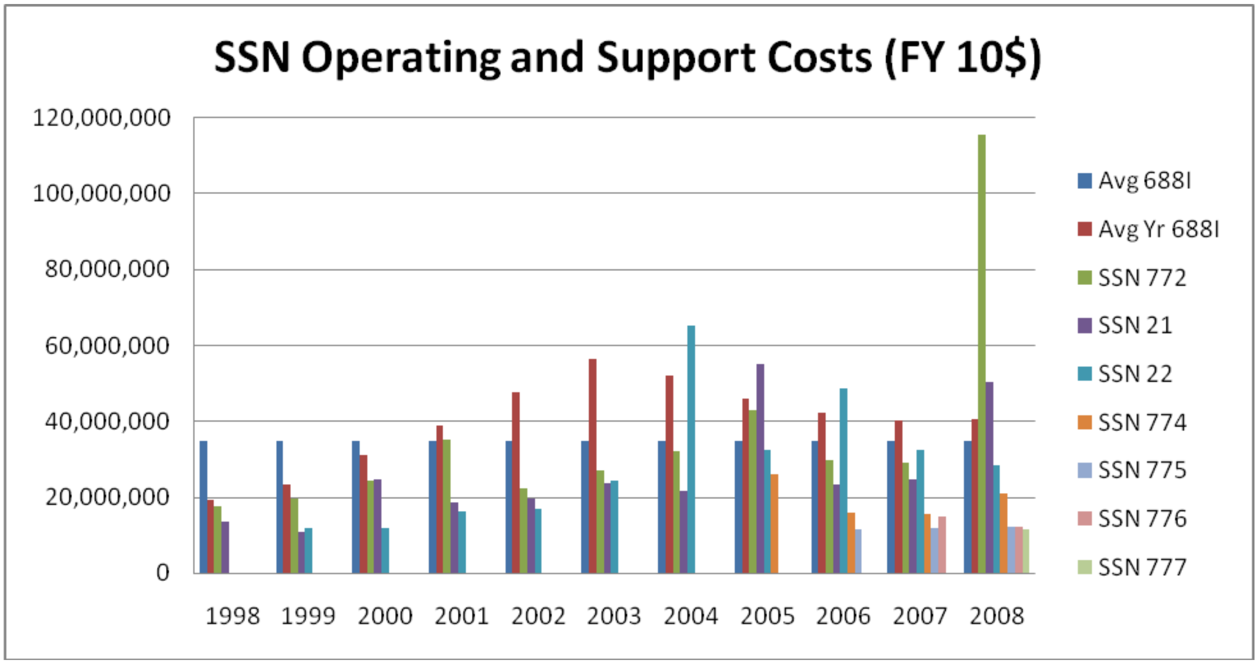

Figure 2

from depot maintenance. Of this number 34 percent is from scheduled depot maintenance ["Cost of CNO-scheduled depot maintenance (e.g., ROH and SRA) incurred at public and private facilities"], and 9 percent is from non-scheduled depot maintenance ("cost of non-scheduled depot level maintenance performed at public or private facilities as a result of casualty, voyage damage, and other unforeseeable occurrences which are beyond the repair capability of O-level and I- level maintenance organizations.")[52]

Still being new, the *Virginia* class ships have not reached any depot maintenance milestones, nor have they had unscheduled depot maintenance in excess of the 688I class average. The highest O&S costs for any of the *Virginia* class were seen on *Virginia* (SSN 774) in

[52] Navy Visibility and Management of Operating and Support Cost Ship Users Manual, 29 January 2010, 37.

2005, and this was driven by a $12 million ammunition training expenditure and not maintenance related.

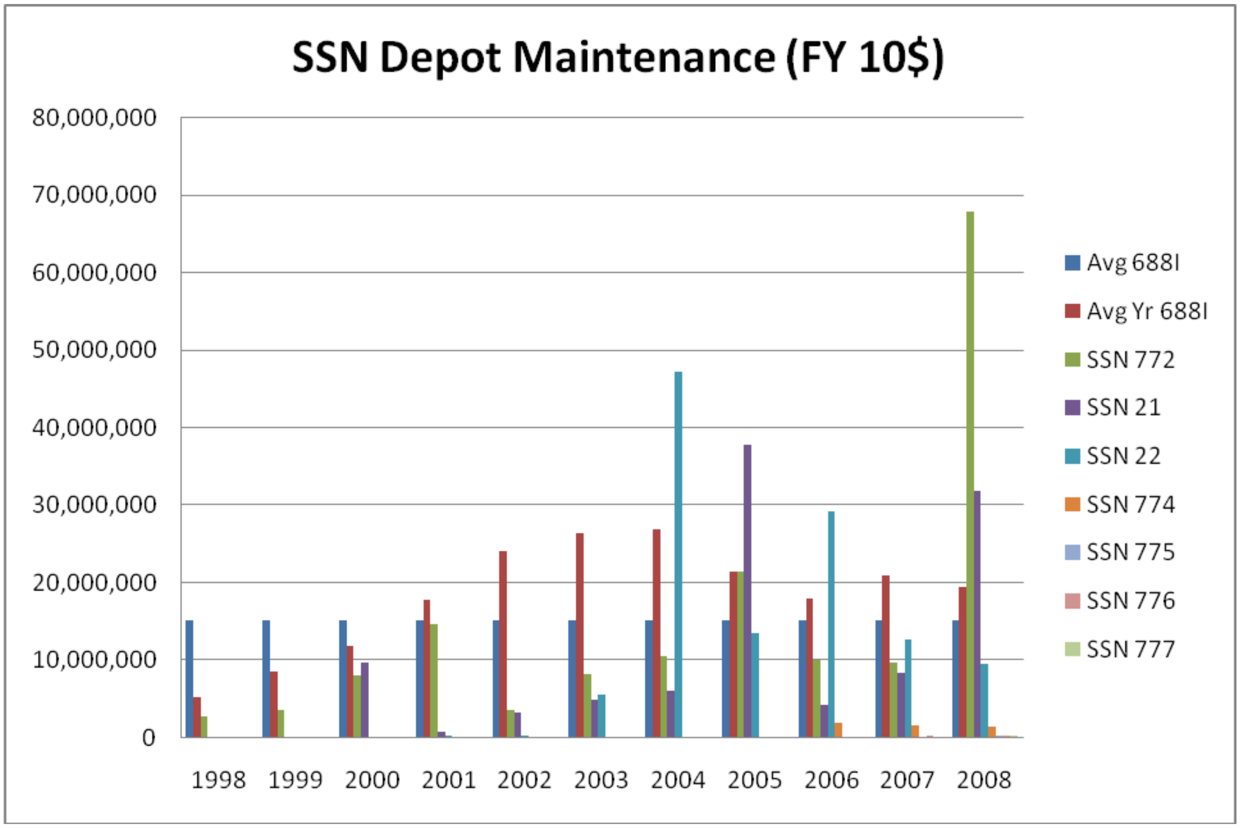

Figure 3

However, both *Seawolf* submarines had unscheduled depot maintenance which exceeded the 688I class average in every year except for 1998 and 1999. Some of the unscheduled depot maintenance on SSN 21 and SSN 22 occurred during their first Docking Selected Restricted Availabilities (DSRA). Originally scheduled as six month maintenance periods, the SSN 21's lasted 16 months due to unforeseen growth in the scope of work. Shipyard loading (Electric Boat was finishing both SSN 23 and SSN 774 during this period) and planning problems related to performing maintenance and inspections for the first time on the *Seawolf* class exacerbated the cost growth. *Seawolf* class depot maintenance continued due to required modernization, including a new combat control system which added to the operating costs for the subsequent years. The combat system modernization was required due to the legacy system no longer being supported as it was designed specifically for the *Seawolf* class.

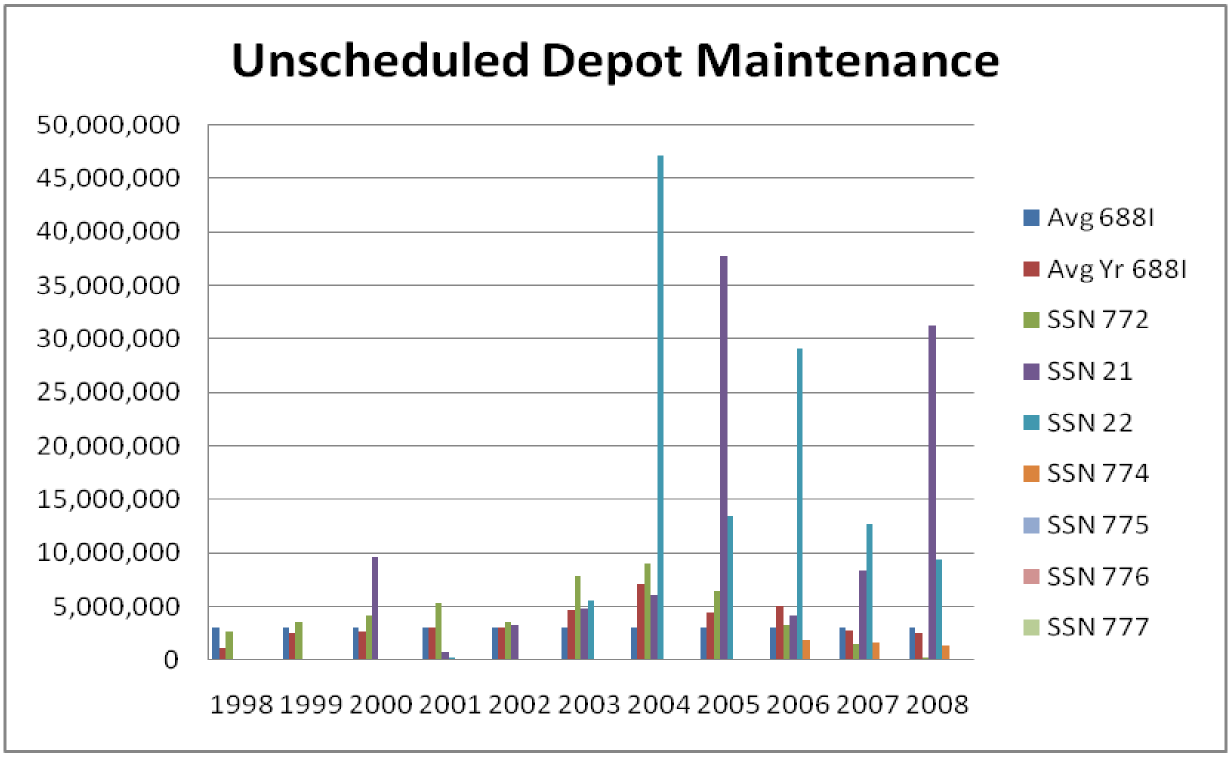

Figure 4

While unscheduled maintenance has been an issue in the *Seawolf* class[53], the 688I class unscheduled depot maintenance cost is $3 billion dollars. This equates to 16 percent of the total 1995 PLCCE depot maintenance estimate for the *Virginia* class.

53 Except for one entry in 2008, all SSN 21class depot maintenance was listed as unscheduled in the VAMOSC data.

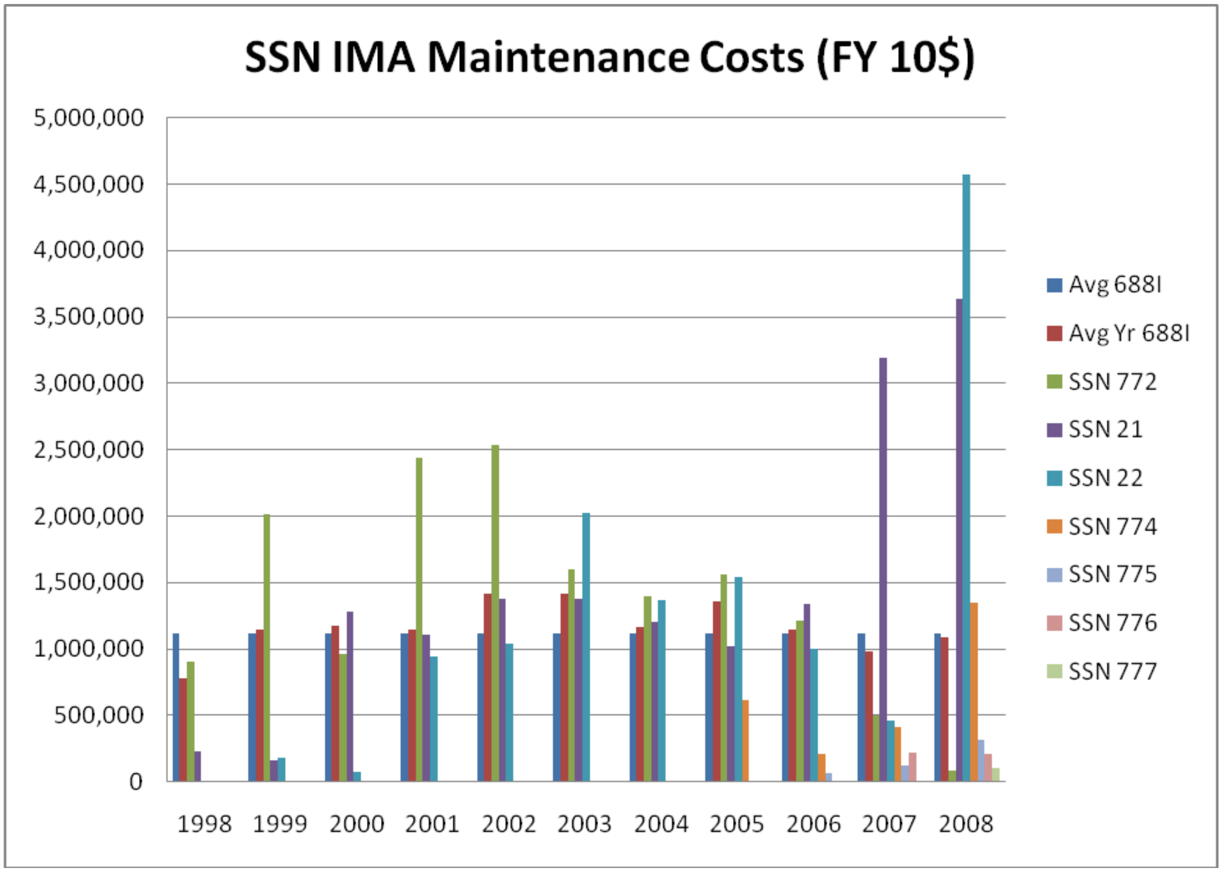

Figure 5

Figure 5 compares the I-level maintenance cost and Figure 6 shows the cost of repair parts associated with ship performed maintenance (O-Level). There is not enough *Virginia* class data to draw any conclusions for the class in any of these categories. As with other new ships (SSN 773 for example), the *Virginia* class ships had lower than 688I class average I-level maintenance costs during their early years of operation. The *Seawolf* class while consistently more expensive than the average 688I, is only slightly more expensive than SSN 772.

SSN 774's repair part costs exceed the 688I average and are comparable to the *Seawolf*' class in two of the four years of operation, but the other three ships do not reflect the same costs. *Seawolf* submarine repair part costs consistently exceed the 688I class average probably as a result of the class specific nature of its parts and their associated high overhead.

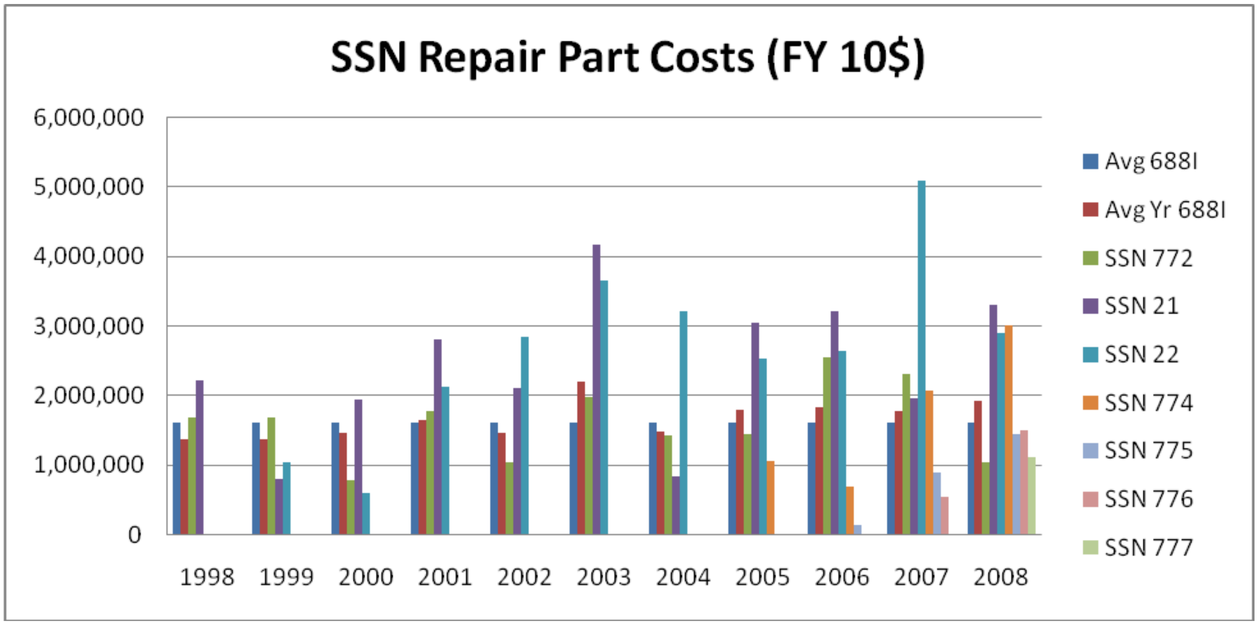

Figure 6

Finally, Figure 7 displays the SSN manpower cost comparison from the VAMOSC data. As the data shows, the *Seawolf* and *Virginia* class costs are relatively equal to the 688I class average. They are the second most significant cost driver on annual operating costs for a submarine O&S costs, making up one-third of the average annual 688I costs.

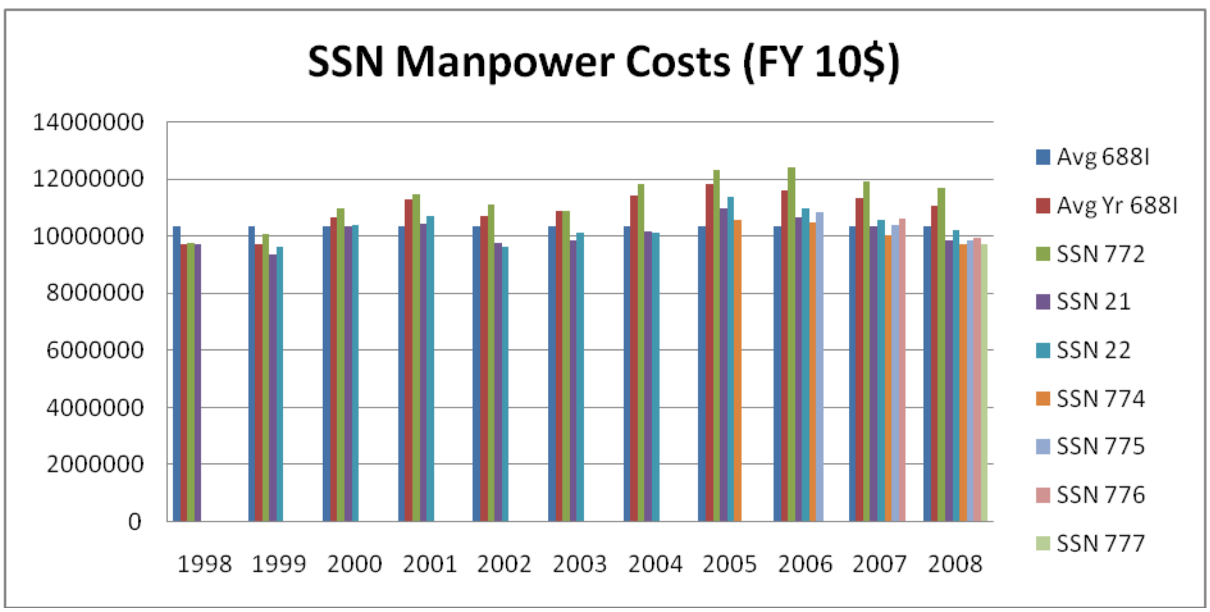

Figure 7

Therefore we can conclude depot maintenance and manpower costs remain the most significant cost drivers. While the *Virginia's* manpower costs remain similar to previous SSN classes, her initial operating costs have avoided the unscheduled depot maintenance which the *Seawolf* class encountered early in her operations. However, it is too early to tell if the *Virginia* class will make the 30 percent TOC reduction from the *Seawolf* class. Finally, the 688I and *Seawolf* classes experienced significant unscheduled depot maintenance which made up 20 percent of the annual 688I depot maintenance costs.

Comparing the Recent *Virginia* Total Ownership Cost Estimates[54]

As the *Virginia* class approached its next milestone review, the *Virginia* class program office reassessed its predicted TOC. Two new estimates were compared to the 1995 PLCCE. The first escalated the original 1995 PLCCE into FY10 dollars. The second is a new TOC estimate performed by Booz Allen Hamilton. Finally, NAVSEA 05C performed a new independent PLCCE. All estimates are discussed in FY10 dollars.

The three TOC estimates ranged from $113 to $175 billion. Figures 6 and 7 compare the estimates in total and by cost category. Figure 7 includes the average 688I O&S data extrapolated for a 30 ship class (estimated size of the *Virginia* class) with a 33 year life per ship. The 1995 PLCCE data used was escalated using the factors obtained from the Joint Inflation Calculator, January 2010 version.

Both of the new estimates predict the 1995 PLCCE undervalued the *Virginia* class TOC. The two new estimate differences were driven by higher acquisition, manpower and depot maintenance costs. The 1995 PLCCE included initial outfitting and modernization costs in the acquisition and depot maintenance categories respectively. The 1995 PLCCE also used the

[54] Booz Allen Hamilton, "*Virginia* Class TOC Baseline Discussion Document". 20 October 2009.

original production schedule to calculate its costs. This schedule changed significantly since the 1995 estimate. In addition, the 2009 PLCCE used *Virginia* class manpower data while the 1995 PLCCE used previous SSN historical data.[55] Manpower costs increased during the interim period. Even with these differences, the O&S costs for the two PLCCE's are relatively similar.

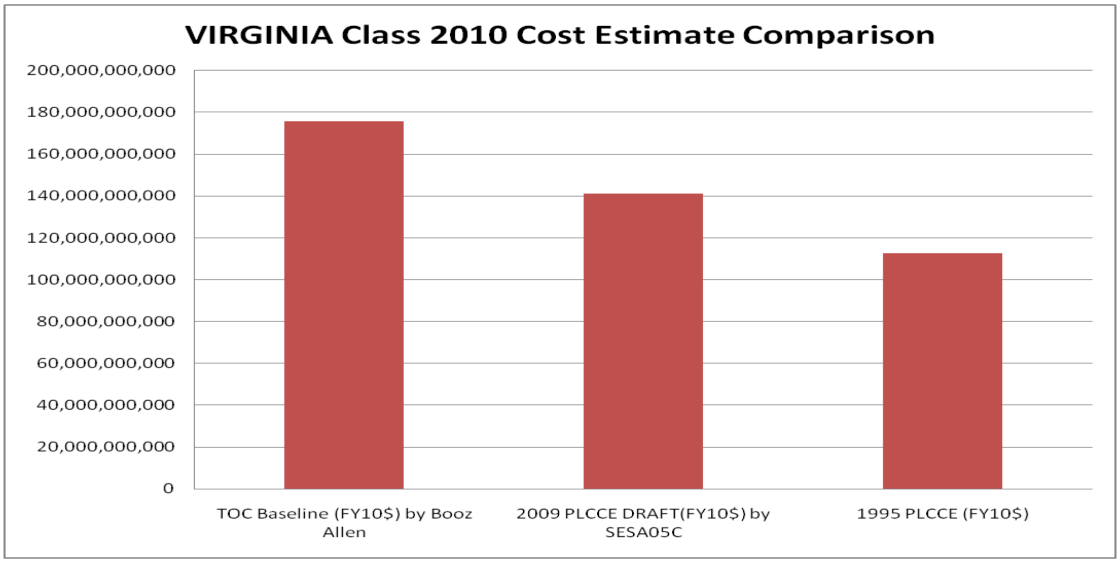

Figure 8

In contrast, the TOC estimate predicts an increase of 71 percent in operating costs compared to the 1995 PLCCE and is 61 percent greater than the 2009 PLCCE operating cost estimate. These differences are driven in order of magnitude by Depot Maintenance ($10B), I-Level Maintenance ($5B), Indirect Support ($4B), Sustaining Support ($4B), and Manpower (3.9B).

Increases in maintenance costs (both D and I-levels) are due to not accounting for overhead / nuclear requirements and changes in the class maintenance estimates. For example, PLCCE I-level maintenance calculations did not incorporate intermediate maintenance support services (including Nuclear) and VAMOSC data corrections,[56] and PLCCE D-Level data did not

[55] "Total Ownership Cost Baseline Estimate Presentation Appendix", PMS 450,
[56] Booz Allen Hamilton, Appendix, Slide 243. VAMOSC data was corrected using Ship's 3M Database which captured maintenance costs not captured in VAMOSC.

incorporate shipyard overhead.[57] Changes in planned depot maintenance drove the largest change in maintenance costs between the TOC and PLCCE estimates. The 1995 and 2009 PLCCEs estimated 38 months of depot maintenance[58] per *Virginia* class ship, while the TOC used a revised plan which included approximately 70 depot maintenance months.[59]

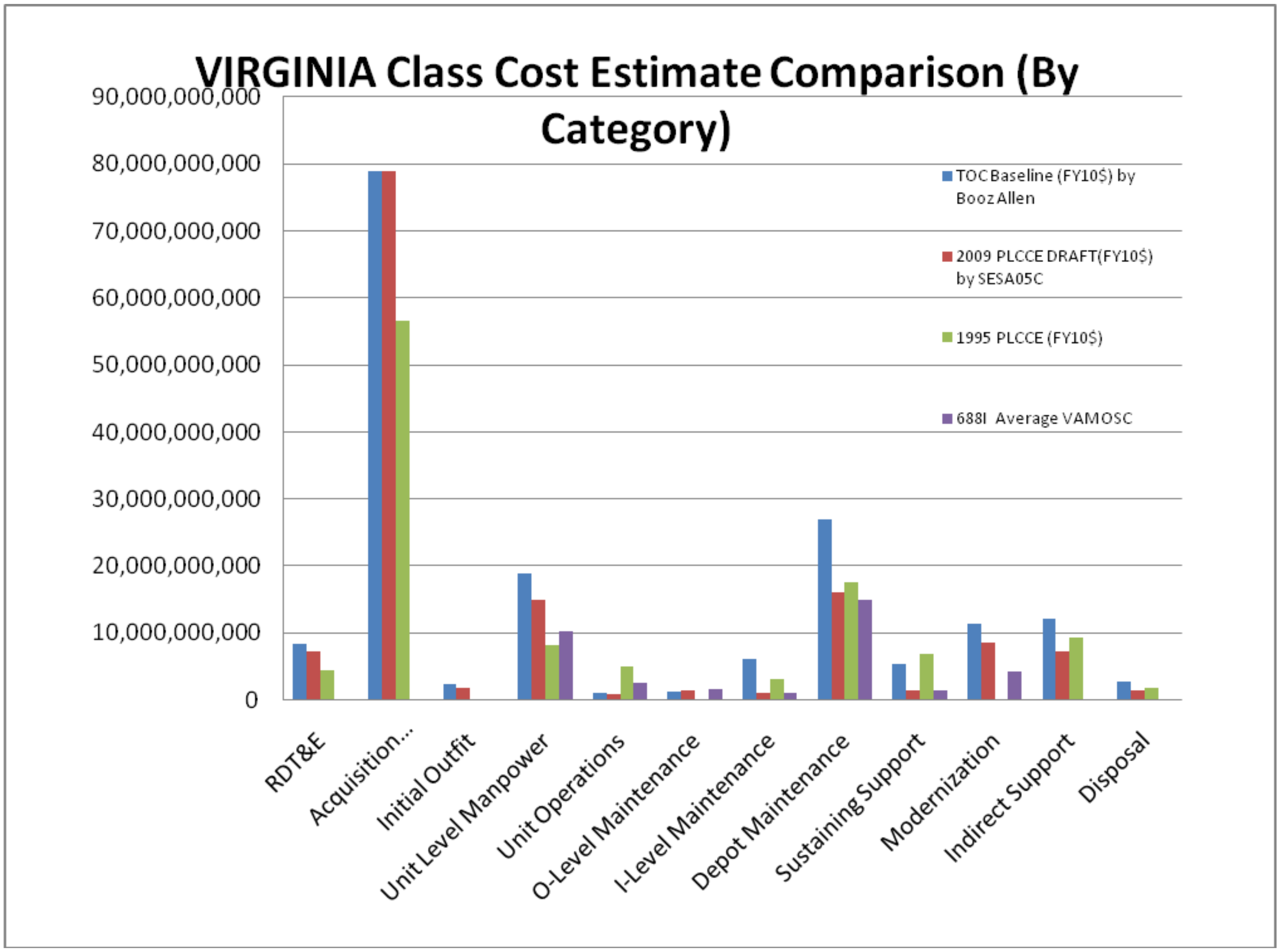

Figure 9

The TOC differences in Sustaining Support and Indirect Support costs are both due to including infrastructure support costs the PLCCE did not cover. For example, the TOC included

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[57] Booz Allen Hamilton , Appendix, Slide 244. A 30% error was assumed on the PLCCE number due to observations that only about 70% of maintenance costs are captured in VAMOSC.

[58] 1997 PLCCE Volume II Back up Data – Mode l Assumptions.

[59] Booz Allen Hamilton , Appendix, slide 162. The plan uses four different schedule models depending on the flight of ship. SSN 774 has the most with 80 months and SSN 782+ the least with 68. Maintenance assessment was in a SHAPEC technical foundation paper released 3 Nov 2008.

program office support costs which amount to about $3.3 billion of the Indirect Support cost difference and these are not in the mandated cost categories a PLCCE uses.

Finally, the TOC estimate expresses concern over the accuracy of VAMOSC data. In many areas the TOC uses a 30 percent correction factor on VAMOSC data or incorporates historical data from some other database for its assessment. While this author cannot confirm this concern, since VAMOSC data is prevalent in many cost studies (1991 Rand Study, the 1995 PLCCE, the 2009 PLCCE) an accuracy check seems warranted.[60]

Conclusions

This paper attempts to show the difficulty inherent in submarine life cycle cost estimation. To do so it looked at three specific questions:

First, what was the root cause of the initial *Virginia* class acquisition cost overruns and could they have been minimized or prevented? The source of the initial cost overruns on the *Virginia* was man hours and material growth. However, the problems were exacerbated because no study on the current vendor base was completed, and as a result, the cost increases were three times what was encountered. In addition, GAO investigations found the shipbuilder anticipated significant cost growth from what was budgeted. Therefore, the growth may not have been preventable, but it could have been minimized.

The next question the paper attempted to answer was how the O&S costs for the *Virginia* class compare to *Seawolf* class and 688I class O&S costs, and did this data change the validity of the program's cost estimates? It is too early to draw conclusions on how *Virginia's* operating costs compare with its predecessor classes. However, the class has avoided the unscheduled depot maintenance that drove the *Seawolf's* early O&S costs. The *Virginia*'s manpower costs are similar to the 688I and *Seawolf* class. Overall SSN manpower cost increases account for the

[60] Booz Allen Hamilton, Slide 162.

increased manpower costs in the latest PLCCE and TOC estimate. The O&S data analysis found that unscheduled depot maintenance accounts for 20 percent of the average 688I depot maintenance costs. If the *Virginia* class continues this trend, its TOC will increase by $3 billion.[61]

The final question answered was how the 1995 PLCCE compared to the 2010 TOC Estimate or the updated NAVSEA 05C PLCCE. These two new estimates showed how the 1995 PLCCE undervalued the TOC of the *Virginia* class. Changes in manpower and depot maintenance drove the increased costs. While the TOC estimate incorporated some costs not considered by the PLCCE, it also used a revised maintenance plan which significantly increased the predicted *Virginia* class O&S costs.

Recommendations

Based on the research, the following recommendations are provided:

1. Cost estimators must recognize the reality of the true expected costs and not allow politics, optimism, or other issues to affect a cost estimate. Former Secretary of the Navy, Donald Winter, warned, "setting targets that are unachievable harms our credibility, creates distrust between Congress and the Navy and destabilizes future budgets as cost overruns come home to roost." Future failures (similar to the initial acquisition *Virginia* class overruns) which cause Nunn-McCurdy breaches, risk the offending program's survival. Cost estimates must reflect realistic estimates and risk factors. They cannot be swayed by politics or budget battles.

2. Program TOC's are driven by acquisition, manpower, and depot maintenance costs. With *Virginia's* depot maintenance plan doubling in size between 1995 and 2010, the *Virginia* class's TOC has risen by 55 percent. An analysis of what caused the *Virginia* depot maintenance

[61] The Booz Allen TOC Baseline assumed only $1 billion of unscheduled maintenance.

plan change should be conducted. This will provide lessons learned to allow future submarine classes to more accurately predict at Milestone B the class depot maintenance costs.

3. Cost estimators rely on historical data to predict future costs. If databases lack fidelity then cost estimates will lack accuracy. With the alleged inconsistencies found with the VAMOSC submarine operating cost data by the Booz Allen Hamilton study, the Navy should assess the VAMOSC databases' accuracy.

4. Finally, unscheduled depot maintenance represented 20 percent of the 688I depot maintenance from 1994 – 2008. This issue warrants additional study to determine the cause of this unscheduled maintenance in order to prevent future occurrences and allow improved O&S cost forecasting.

In conclusion, there is no question the *Virginia* class is successfully managing the acquisition phase. Its leaders have worked to correct cost overruns as they occur. However, its TOC growth due to depot maintenance remains an issue and could impact the class's ability to achieve its TOC reduction goals. Increased operating costs make fleet commanders decide which ship will get the available depot maintenance funds as resources become scarce, resulting in reduced submarine operations tempo. Therefore, the ability of the SSN force to meet operational requirements relies on the *Virginia* Program's ability to achieve its current cost goals.[62]

[62] Young, John J. Statement to Senate Armed Services Committee, 3.

Appendix A

Cost Estimating Methods – printed from the *Cost Estimating and Assessment Guide* produced by the Government Accounting Office, March 2009. GAO 09-3SP.

Cost Estimating Methods

The three commonly used methods for estimating costs are analogy, engineering build-up, and parametric. An analogy uses the cost of a similar program to estimate the new program and adjusts for differences. The engineering build-up method develops the cost estimate at the lowest level of the WBS, one piece at a time, and the sum of the pieces becomes the estimate. The parametric method relates cost to one or more technical, performance, cost, or program parameters, using a statistical relationship.

Which method to select depends on where the program is in its life cycle. Early in the program,

Method	Strength	Weakness	Application
Analogy	▪ Requires few data ▪ Based on actual data ▪ Reasonably quick ▪ Good audit trail	▪ Subjective adjustments ▪ Accuracy depends on similarity of items ▪ Difficult to assess effect of design change ▪ Blind to cost drivers	▪ When few data are available ▪ Rough-order-of-magnitude estimate ▪ Cross-check
Engineering build-up	▪ Easily audited ▪ Sensitive to labor rates ▪ Tracks vendor quotes ▪ Time honored	▪ Requires detailed design ▪ Slow and laborious ▪ Cumbersome	▪ Production estimating ▪ Software development ▪ Negotiations
Parametric	▪ Reasonably quick ▪ Encourages discipline ▪ Good audit trail ▪ Objective, little bias ▪ Cost driver visibility ▪ Incorporates real-world effects (funding, technical, risk)	▪ Lacks detail ▪ Model investment ▪ Cultural barriers ▪ Need to understand model's behavior	▪ Budgetary estimates ▪ Design-to-cost trade studies ▪ Cross-check ▪ Baseline estimate ▪ Cost goal allocations

definition is limited and costs may not have accrued. Once a program is in production, cost and technical data from the development phase can be used to estimate the remainder of the program. The table above gives an overview of the strengths, weaknesses, and applications of the three methods.

Other cost estimating methods include

■ expert opinion, which relies on subject matter experts to give their opinion on what an element should cost

■ extrapolating, which uses actual costs and data from prototypes to predict the cost of future elements; and

■ learning curves, which is a common form of extrapolating from actual costs.

Appendix B

688I Operations and Support Data Analysis

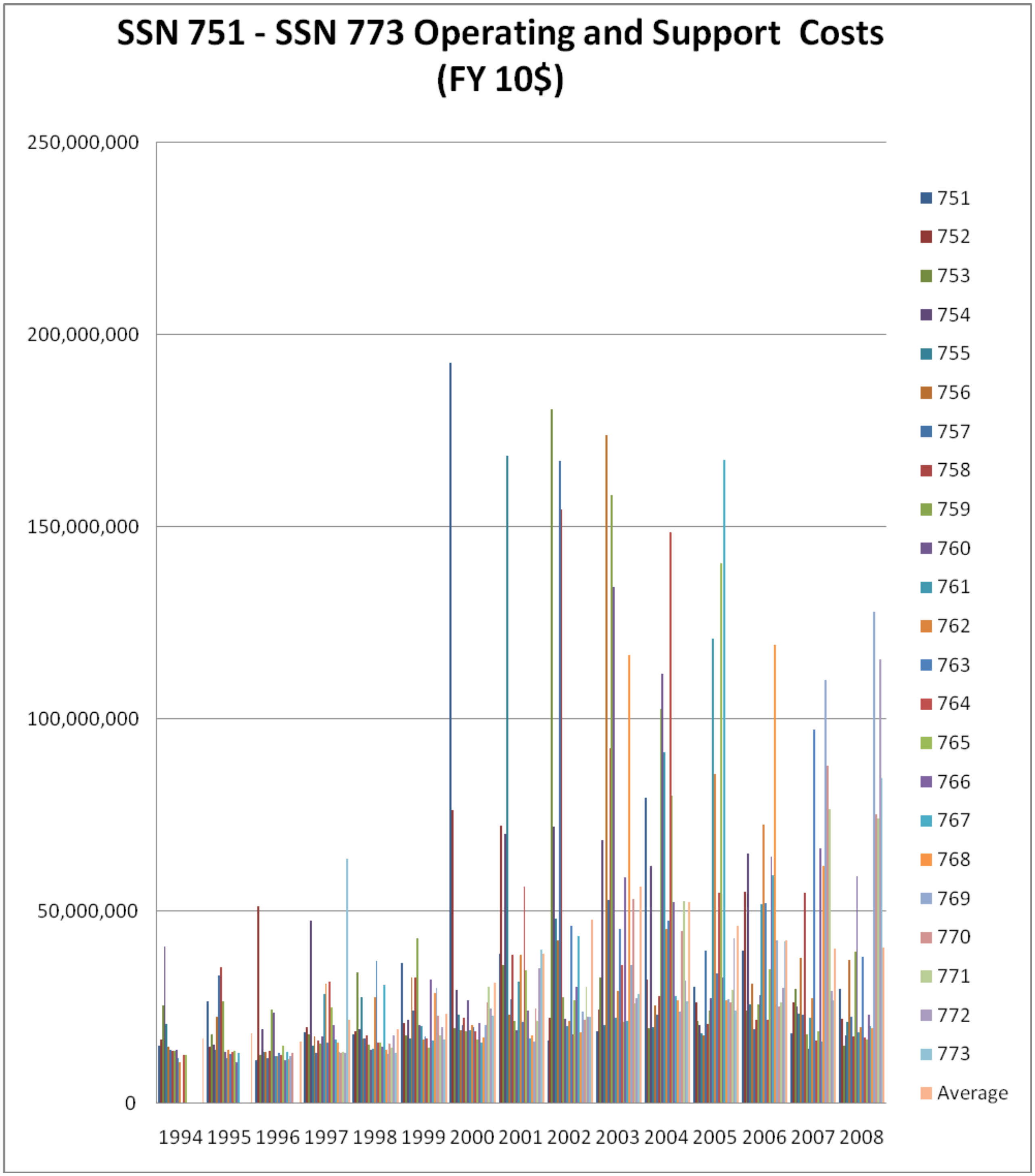
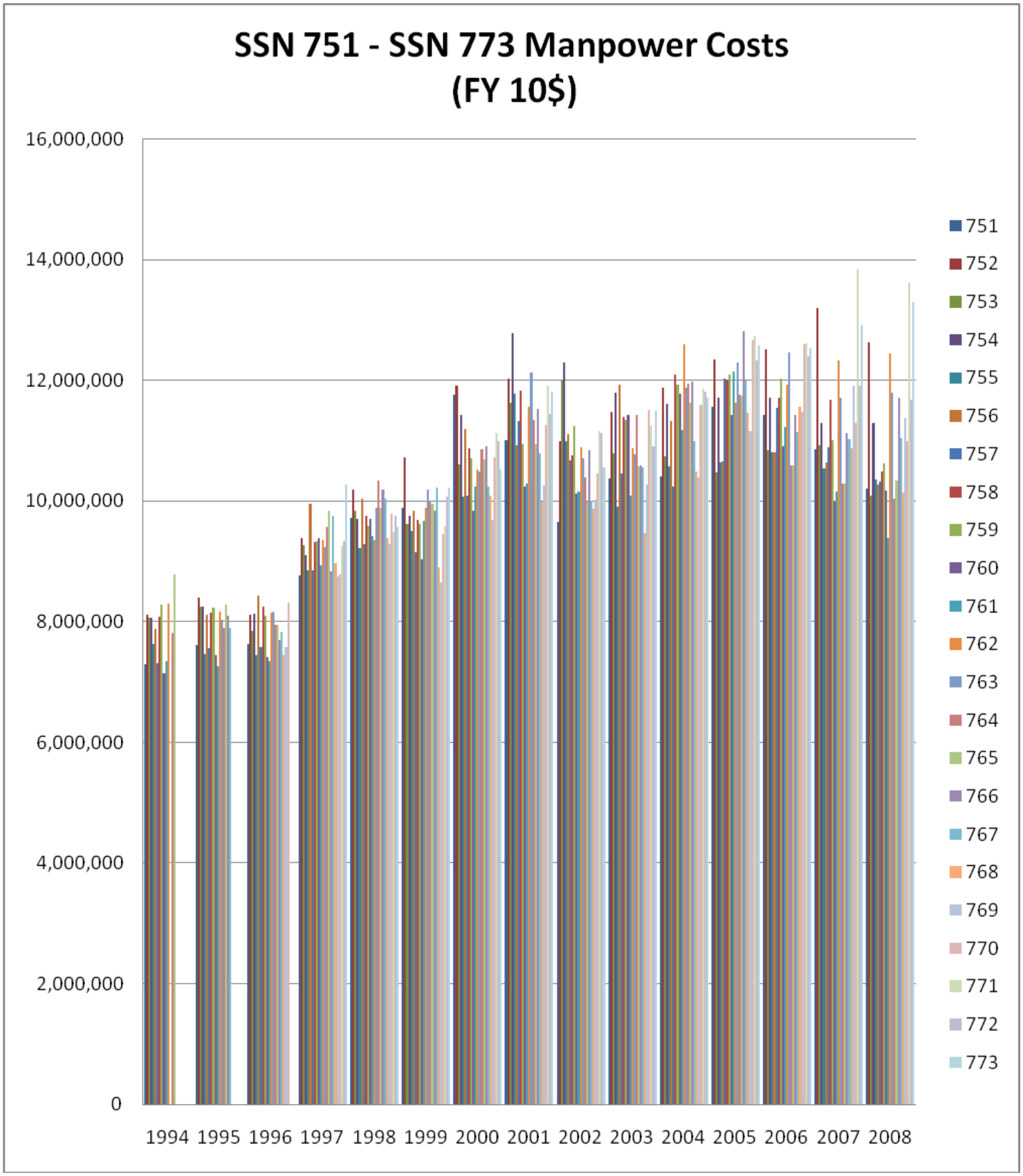


Figure 10


SSN 751 - SSN 773 Manpower Costs
(FY 10$)
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
751
752
753
754
755
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760
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762
763
764
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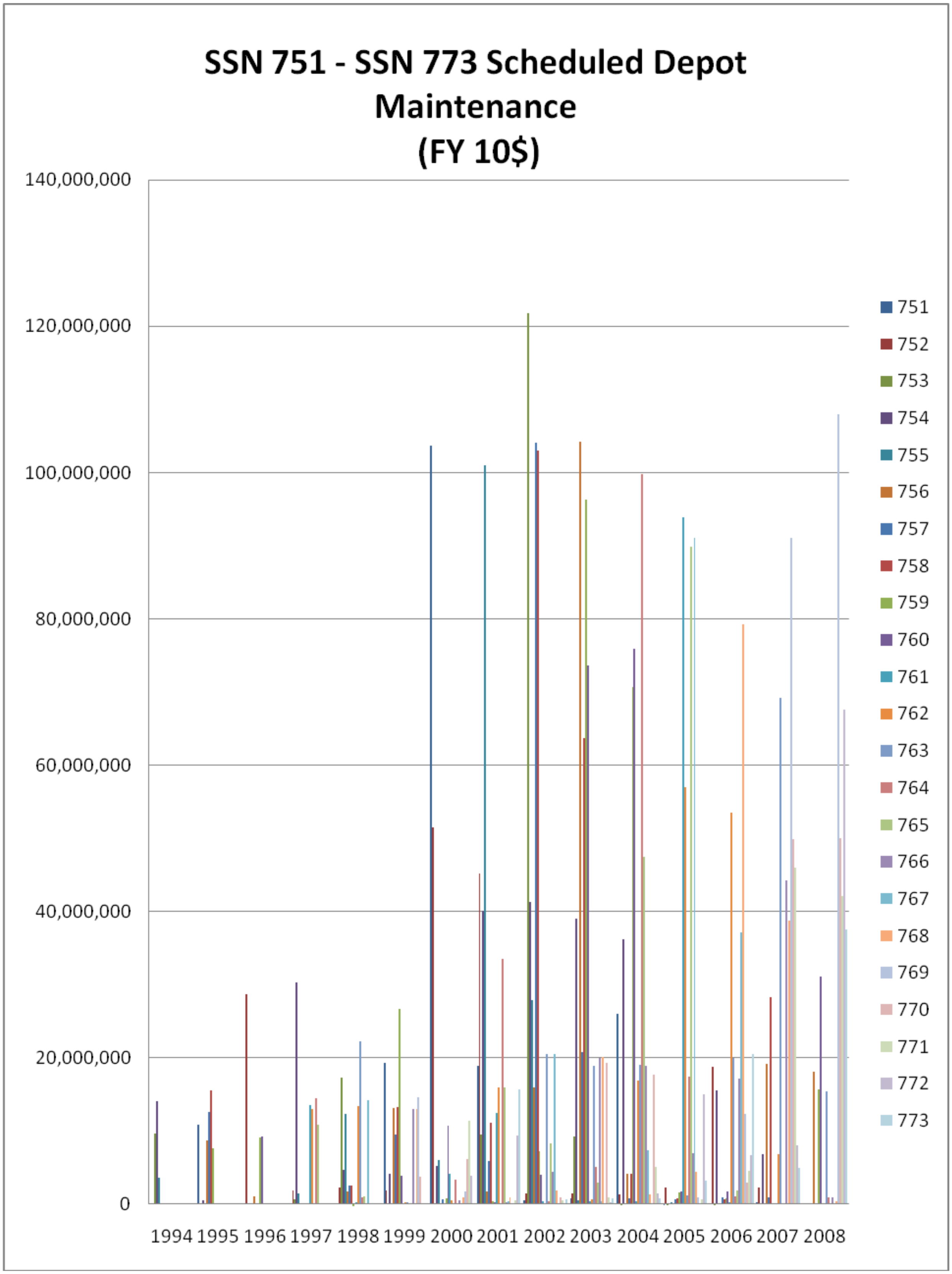
768
769
770
771
772
773

Figure 11



SSN 751 - SSN 773 Scheduled Depot Maintenance
(FY 10$)
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
751
752
753
754
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756
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758
759
760
761
762
763
764
765
766
767
768
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771
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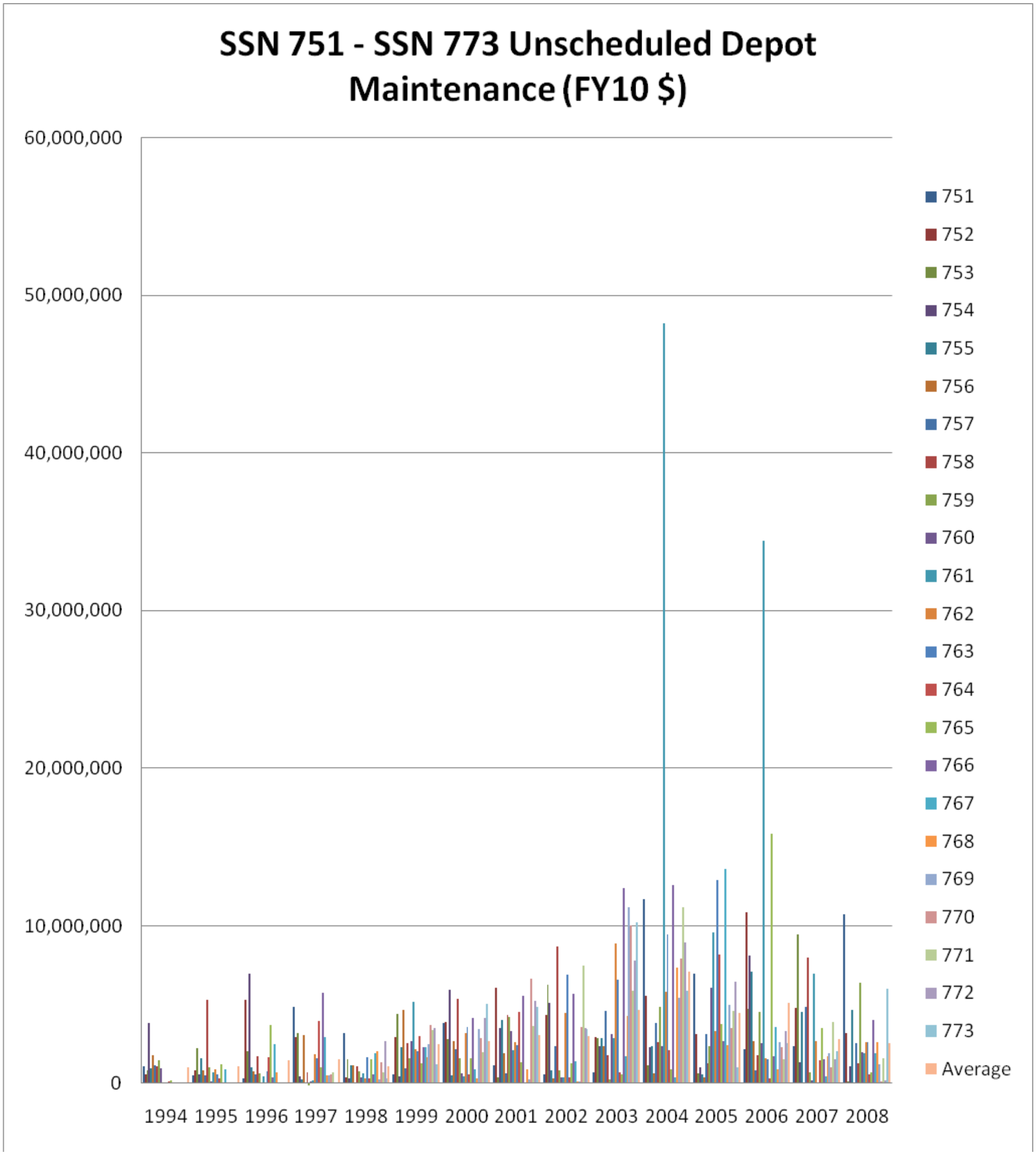
Figure 7



SSN 751 - SSN 773 Unscheduled Depot Maintenance (FY10 $)
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
751
752
753
754
755
756
757
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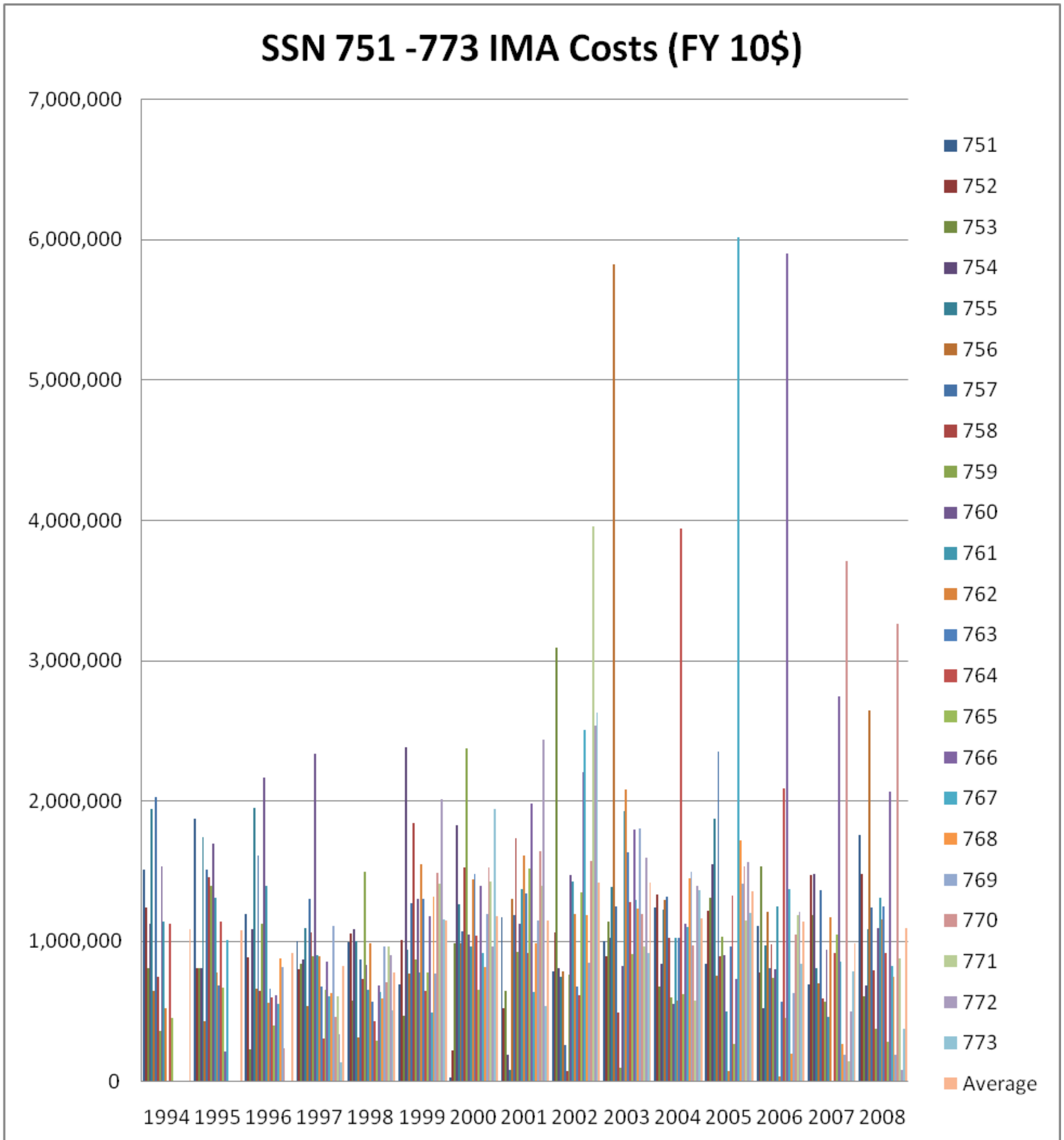
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
Average

Figure 13



SSN 751 -773 IMA Costs (FY 10$)
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
751
752
753
754
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760
761
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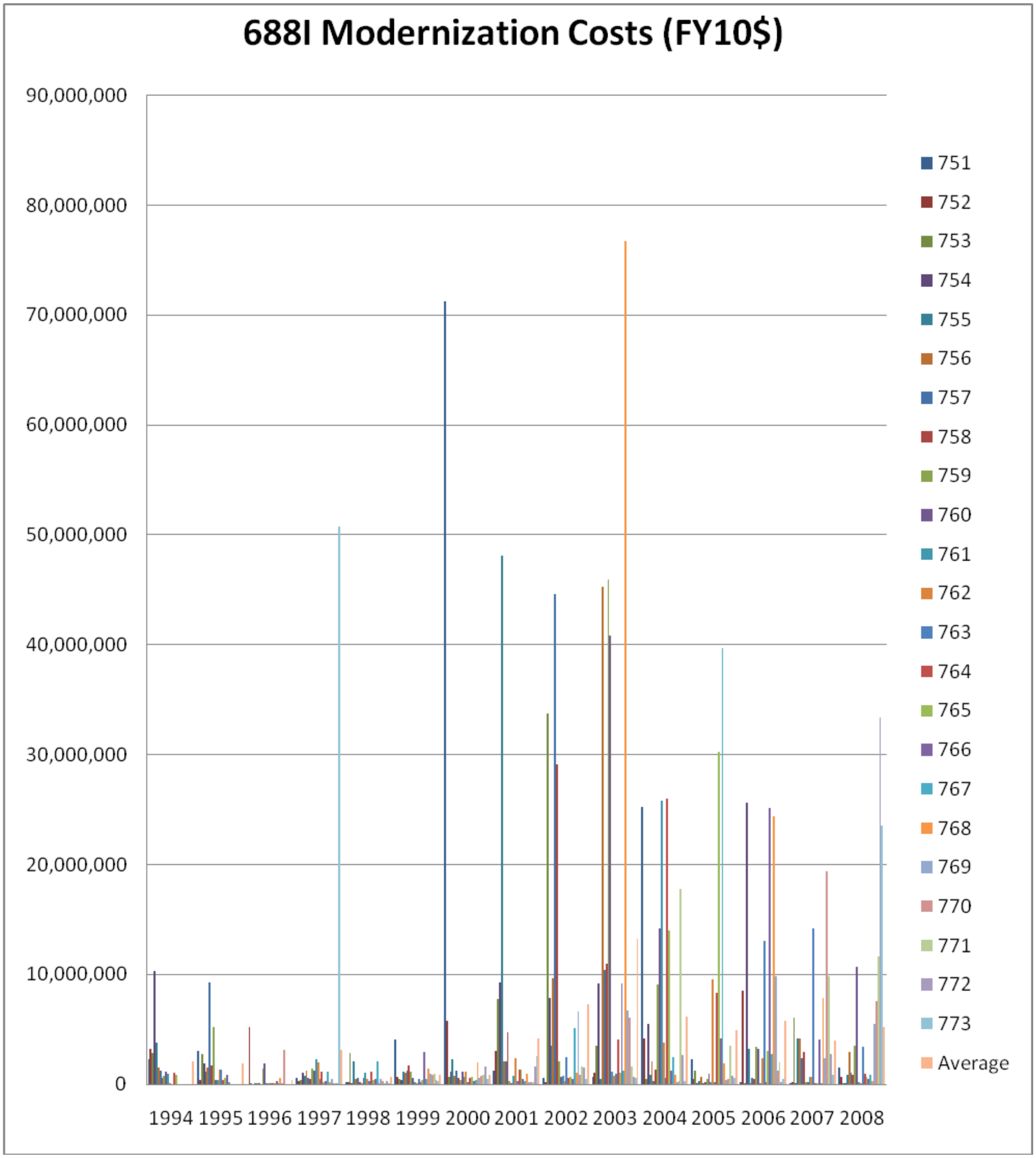
763
764
765
766
767
768
769
770
771
772
773
Average

Figure 148


688I Modernization Costs (FY10$)
90,000,000
80,000,000
70,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
751
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753
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755
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758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
Average

Figure 15

Appendix C

688-Class O&S Cost Study Results

688-Class Submarine O&S Costs (FY91$)

Description	Cost ($ million)	Hull Numbers	Timing
Average annual O&S Cost (excluding major depot availabilities)	$15	All	Annual
Regular overhaul (ROH)	$175	688–699	7th year
Depot modernization period (DMP)	$90	700–773	7th year
Engineered refueling overhaul (ERO)	$265	688–718	16th year
		719–773	24th year
Engineered overhaul (EOH)	$175	688–718	24th year
		719–773	16th year
Inactivation (INAC)	$50	All	30th year

Reprinted from *The U.S. Submarine Production Base* by John Birkler, John Schank, Giles Smith, Fred Timson, James Chiesa, Marc Goldberg, Michael Mattock, and Malcom Mackinnon. Rand Corporation, 1994, pg. 192.

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